

# **CANADIAN AMMUNITION STORAGE MAGAZINES**

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CANADA**

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# CANADIAN AMMUNITION STORAGE MAGAZINES

BY

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## A B S T R A C T

Canada's ammunition storage magazines, designed by the departmental engineers, can rightfully qualify for the title " The World's largest igloos " given their unprecedented characteristics in terms of structural engineering features ( reinforced concrete box structure with a clear span of 17m, depth 28m and clear height of 5.7m ) and storage capacity of 250,000 kg. of equivalent TNT of Hazard class/div 1.1. This paper describes the design criteria, design methodology, construction, cost and various requirements of safety, security, operation etc. employed in these magazines. Currently, 17 igloos have already been constructed and 11 others with reduced capacity but similar structural engineering features are being planned for construction in the summer of 1992. The siting of the battery of igloos is such that the static design required for the normal environmental loads is adequate to carry the large dynamic blast loads from accidental explosions without the undue premium usually paid to achieve blast resistant facilities. Special attention is drawn to the design controlled by the blast loads on the roof, and not on the head wall as seen in many short span igloos.

## 1. INTRODUCTION

The Canadian Forces Ammunition Depots are located across Canada in the varying climates of the country. Many of the ammunition storage facilities in these depots date back to the days of the second world war. Ammunitions are stored in various ways i.e. out in the open (Fig. 1) or inside of magazines of different forms of construction such as wood, steel Quonset huts, concrete block wall, precast panel wall etc.(Fig. 2). It has been determined that most of these magazines are deficient in many respects and do not meet the modern day requirements of safety, security, shelter, operation and long term warehousing.

Some deficiencies of the existing facilities are as follows:

- a. The layout, with interior columns and/or load bearing walls, is awkward and inefficient in terms of operation and storage.
- b. Low ceilings prevent the use of modern handling equipments and inhibit proper management of palletized stacks.
- c. Untraversed magazines pose considerable threat to the surroundings in case of accidental explosions.
- d. Traversed magazines have insufficient earth cover i.e. 0.15m on the roof which cannot carry any additional loads.
- e. Insufficient ventilation in the magazines results in damp musty air conditions within the buildings.
- f. Evidence of decay and rot in wooden magazines.
- g. Temperature extremes within the steel Quonset magazines limit the life span of stored ammunitions.
- h. Wood-core doors provide inadequate security and protection against accidental blast effects.

## 2. DEVELOPMENT OF STANDARD MAGAZINE

Hence, the Canadian Forces has embarked on a magazine replacement program with the development of a standard magazine to accommodate the long term warehousing requirements, maximize storage efficiency and improve safety and operations. Though the

inventory of ammunitions range from Hazard Division (HD) 1.1 to 1.4, the standard magazine is developed to house a Net Explosive Quantity ( NEQ ) of 250,000 Kg of equivalent TNT of HD 1.1. While this may result in some over design, this provides flexibility to the depot's operations without dedicating specific magazines to specific hazard divisions, given that the amount and nature of warehousing may vary throughout the year.

Figs. 3 & 4 show a schematic layout and details of the standard magazine based on 215 Kg of NEQ /cu.m of stack volume. The design also allows for a clear and column free operational aisle, fire inspection aisles and a wide sliding door. Thus, the " World's largest igloo " was launched into design to house an unprecedented NEQ of 250,000 Kg. of HD 1.1 within a structure of an equally unprecedented proportions of 17m clear span, 28m deep and 5.7m high.

### 3. DESIGN CRITERIA

#### .1 Safety

- a. The structure should resist all normal loads such as its own weight, earth, snow and live loads on roof and lateral earth pressures on walls.
- b. An accidental explosion within one magazine i.e. the donor should not result in propagation of detonations in adjacent magazines i.e. the acceptors. The donor is not expected to survive the accidental explosion from within it. There is no explicit requirement to either save or limit the level of damage to the acceptor.
- c. Blast, fragments and fire associated with an accidental explosion within a donor should not pose significant hazard to other inhabited structures and public traffic routes in the vicinity.

#### .2 Security

- a. Stored materials should be protected from direct hits with small arms and damage from indigenous animals.
- b. Unauthorized access to the stored materials should be prevented. An independant utility room adjacent to each magazine is provided in addition to an intrusion alarm system.

### **.3 Shelter**

- a. Materials and their packaging should be protected from moisture induced degradation.
- b. Materials should be sheltered from extremes of temperature fluctuations.
- c. The structure should protect its contents from external fire, lightning strikes etc.

### **.4 Operation**

- a. Storage area should be maximized.
- b. Operating aisle should allow for the use of 2-ton fork lift trucks.
- c. Doors should be wide enough to accommodate the backing of ammunition loaded trailers into the structure.
- d. Smooth transition from the apron exterior to the structure interior floor is essential.
- e. Vertical clearance should provide for long term stacking height of 5 pallets.

## **4. DESIGN METHODOLOGY**

### **.1 DESIGN FOR NORMAL LOADS ( STATIC )**

- a. The structure is analyzed as a 2-dimensional portal frame for all normal loads such as dead weight, earth, snow and live load on roof and lateral earth pressure on walls ( Fig.5).
- b. The results of the frame analysis are modified to account for the two-way slab action of the roof slab. This is done by reducing all the values obtained from the roof in the 2-D analysis by a reduction factor. This factor is determined to be the average of the values obtained from frame analysis and the two-way slab analysis at both support and mid-span locations. Further refinements using 3-D finite element analysis of a box structure is not considered essential, given that the applied loads are generally uniform. Fig. 6 shows some representative values of member forces

obtained from this analysis. -

c. According to the National Building Code of Canada ( Ref.1), the building structure is designed using the limit states design for various load and load combination factors ( Fig. 7).

d. The results of the normal load analysis clearly illustrate the optimum level of design achieved in the structure without excess capacity ( Fig. 8 ).

## **.2 DESIGN FOR ACCIDENTAL BLAST LOADS ( DYNAMIC )**

### **SPACING OF IGLOOS AND CALCULATIONS OF BLAST LOADS**

a. A literature survey of the igloos designed and constructed in the past ( Refs. 2 & 4 ) indicates the following:

- span of igloos about half as that of the Canadian igloo.
- design NEQs smaller than that of the Canadian NEQ.
- no consistency in the evaluation of blast loads.
- igloos spaced at the so called " Standard Scaled Distances ".

b. Given the immense structural dimensions and the NEQ of the Canadian igloo, the application or extrapolation of existing data in the design process raised some concerns. Consequently, assistance was sought from the late Dr. Wilfred Baker of U.S., an eminent authority on blast physics, in determining the design blast loads for the Canadian igloo.

c. After studying references 5, 6 & 7, Dr. Baker concluded that the results obtained from model igloos listed in Ref. 5 could be used for the Canadian design. Based on Ref. 5, Pressure-Distance and Scaled Impulse-Distance diagrams were constructed by Dr.Baker ( Fig. 9 & 10 ). Figs. 11 & 12 show comparisons between the design curves recommended by Dr.Baker and those obtained from a more recent study ( Ref.8 ). While some similarities exist, differences are also noted between the two methods giving rise to the continuing concern about the accuracy of the prediction of air blast loads from igloos.

d. In laying out the igloos, various positions for

the front to back and side to side siting were attempted before arriving at the final front-back distance of 90m and side-side distance of 35m ( Figs. 13 & 14 ).

e. The Canadian igloos are located at scaled distances ( $m/Kg^{.33}$ ) of front to back 1.43 ( Standard 0.8 ) and side to side 0.56 ( Standard 0.5 ). The siting distances are controlled by the magnitude of blast loads on the long span roof and not by the reflected pressures on the front wall/door, as noted in many short span igloos. Fig. 15 lists the various pressure-impulse combinations acting on the elements of an acceptor assuming that any igloo can become a potential explosion site within the battery of igloos.

#### DYNAMIC DESIGN OF ELEMENTS

a. Each element is considered as a separate component i.e. roof as a two-way slab component, side and rear walls as one-way vertical components, front wall as a two-way component and door as a one-way horizontal component between the pilasters. The roof also acts as a horizontal diaphragm between the end walls transferring the lateral blast loads to the foundation through shear wall action.

b. Calculations of dynamic properties and the response of the elements using single degree of freedom analysis are performed in accordance with Ref.3 with appropriate adjustments made to accommodate the Canadian Codes. For reinforced concrete, Type II sections as in Ref.3 are employed.

c. Fig.16 shows the resistance-deflection characteristics of the roof slab based on three different end conditions. In the case of wall continuity, the ultimate support moment for the roof slab is restricted to that provided by the wall at the roof-wall junctions. Fig.17 indicates the idealized equivalent resistance diagram which is determined after making allowance for the dead load and weight of earth that act continuously on the roof. Fig.18 shows an alternative method of calculation by reducing the ultimate resistance by the amount of dead load and weight of earth. In this case, the available resistance diagram is as shown in the figure. Fig.19 summarizes the results obtained by both methods and shows little difference in this instance. The maximum dynamic displacement for the roof slab is about 400mm and is included in the vertical clearance. A similar



resistance-deflection curve obtained for the one-way rear wall element is shown in Fig.20. Adjustments similar to the one for the roof dead load are made to this curve to account for the lateral earth pressure acting on the wall.

d. A summary of the dynamic response obtained for all the elements is shown in Fig.21. Again, it is noted that the dynamic design is also optimized without excessive reserve capacity.

e. Figs.22 & 23 show details of the igloo and the hanging sliding door including the locking mechanism.

#### CRATERING EFFECTS

Being a standard design, calculations are performed to determine the true crater dimensions in all types of ground conditions ( Fig.24 ). These calculations indicate that the igloos are located well beyond the crater limits. In these calculations, the effect of the nominally reinforced 300mm thick floor slab has been ignored. If taken into account, this should further minimize the extent of true cratering.

#### UTILITY ROOM

This is not specifically designed to be blast resistant like the igloo. However, some mass is provided in the building with 400mm thick nominally reinforced walls and roof that are capable of resisting some nominal blast loads.

### 5. CONSTRUCTION FEATURES

a. The sequence of construction has varied from contractor to contractor depending on the number of igloos in the contract. In a recent contract involving sixteen igloos, the following sequence was found to be convenient:

- foundations for all walls were laid first.
- the rear wall and the side walls upto about 9m from the rear wall were poured upto the horizontal construction joint.
- the remaining side walls upto a meter from the front wall were poured upto the horizontal construction joint.
- the floor slab was cast in two stages i.e. the rear three-quarter portion first followed by the

remaining front portion except the entry ramp. Completion of floor slab before casting the front wall provides free access to the floor construction. This also prevents heat build up within the walls of the igloo during the summer months which affects the finishing operations on the floor.

- the front wall including the pilaster, the canopy and the remaining portions of the side walls were poured upto the construction joint (Fig.26 )
- the roof slab was poured as one unit ( Figs.25 & 29 )
- the entry ramp and the front concrete sill were completed.
- retaining walls and the utility room were completed.
- the sliding door was hung from the runner beam under the canopy ( Fig.28 )
- finally, all waterproofing, insulation and earth traverse were placed sequentially ( Fig.30 )

b. It is very important that the roof slab is not allowed to act as a one-way slab during construction as the residual strength available to handle the construction loads will not be adequate. Consequently, the construction should allow for immediate shoring under the roof slab after the removal of the forms and that the shoring shall remain in place until the whole roof slab is cast to comply with the design requirements of a two-way slab slab action( Fig.27 ).

c. Fig.31 shows the concrete strengths obtained in the various magazines. They are consistently well above the design requirements. Due to the congestion of reinforcement in areas like the pilaster, superplasticizers were permitted in these localized areas. In spite of this, honeycombing occurred in some areas and had to be remedied.

d. Since the ends of the roof and walls are designed to be within 2 to 4 degrees rotations, double leg stirrups are placed in a staggered fashion throughout to ensure post-elastic behaviour.

e. The slope of the earth traverse on the sides and rear is 1:3, flatter than usual to facilitate maintenance. Besides, flatter slope improves the blast loading characteristics on the mounded igloo structure. The traverse is compacted to 95 percent proctor density while the earth covering over the roof is compacted to 80 percent.

f. An exterior lightning protection system on poles is provided over each igloo. In addition, all reinforcement in roof and walls, metal ventilators and door are electrically

bonded and grounded.

g. The igloo is also equipped with an intrusion alarm system, an automatic sprinkler system and a hot water radiant heating system.

h. A natural ventilation system with air intakes and chimney outlets is provided. All openings into and from the igloo are protected with security grills and insect screens.

## 6. COSTS

a. At the time of writing this paper, another contract is being tendered for the construction of 11 igloos with reduced capacity of 40,000 Kg. of NEQ /igloo but with similar structural dimensions ( Figs.32 & 33 ). In this case, the scaled distances are front-back 1.02 and side-side 0.64.

b. However, many igloos have already been constructed. Fig.34 provides a summary of the total project cost including all ancillary costs. It is interesting to note that the cost per Kg. of NEQ stored reduces as the NEQ increases. The two earlier igloos shown in Fig.34 have cranes on gantry beams for interior operations.

## 7. CONCLUSIONS

a. An optimum design has been achieved for the Canadian igloo to withstand both normal and accidental blast loads. Very little premium in the form of special double leg stirrups is paid to achieve the blast resistant capabilities.

b. Intermagazine distances are greater than the so called standard spacings used for igloos. This is due to the design being controlled by blast loads on the large span roof instead of the loads on the front wall/door, as noted in many short span igloos.

c. The Canadian igloo provides for storage efficiency and ease of operation with column free interior, wide doors and locally depressed floor slab for smooth entry from the apron exterior to the structure interior.

d. The Canadian igloo can rightfully earn the title " The World's Largest Igloo " with its unprecedented structural dimensions and the immense NEQ capacity.

## 8. REFERENCES

1. National Building Code of Canada
2. Canadian Explosives Safety manual  
( C-09-153-001 )
3. Structures to resist the effects of accidental explosions  
( ARLCD-SP-84001 )
4. Manual on NATO Safety Principles for the storage of  
Ammunition and Explosives  
( AC258-D258 )
5. Blast parameters from explosions in model earth covered  
magazines  
( BRL MR 2680 )
6. ESKIMO - VI Model Tests  
( ARBRL-TR-02215 )
7. ESKIMO - VI Test results  
( NCEL TR R889 )
8. A re-examination of the airblast and debris produced by  
explosions inside earth-covered igloos  
( NAVSWC TR 91-102 )

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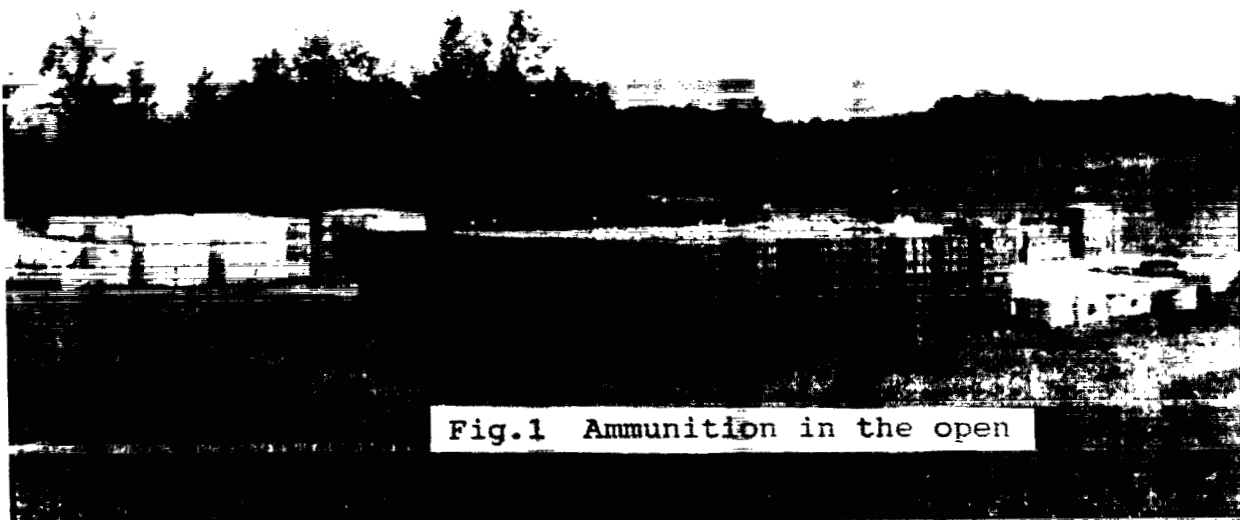


Fig.1 Ammunition in the open

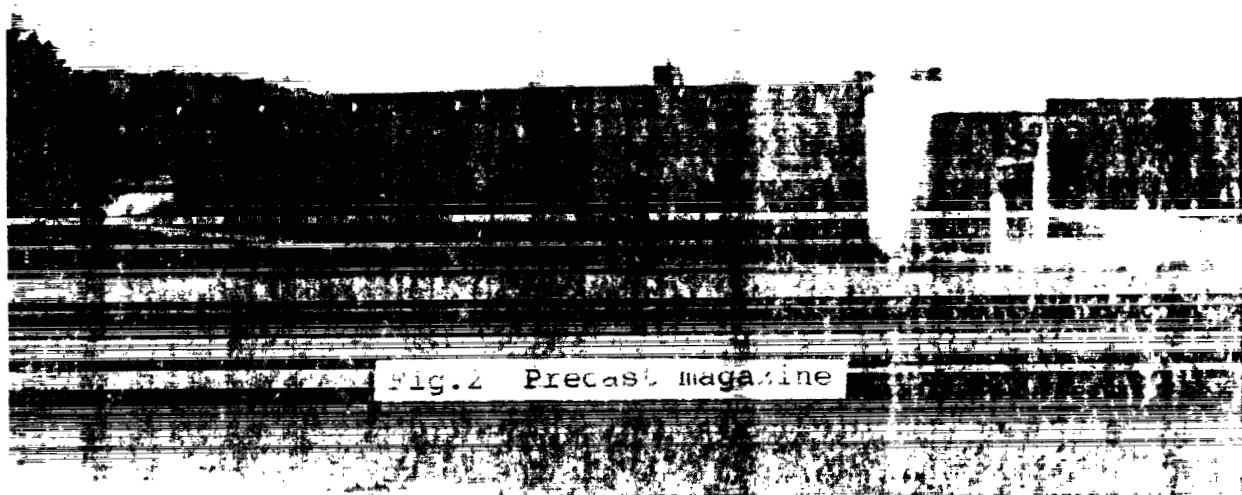


Fig.2 Precast magazine

## AMMUNITION STORAGE LAYOUT

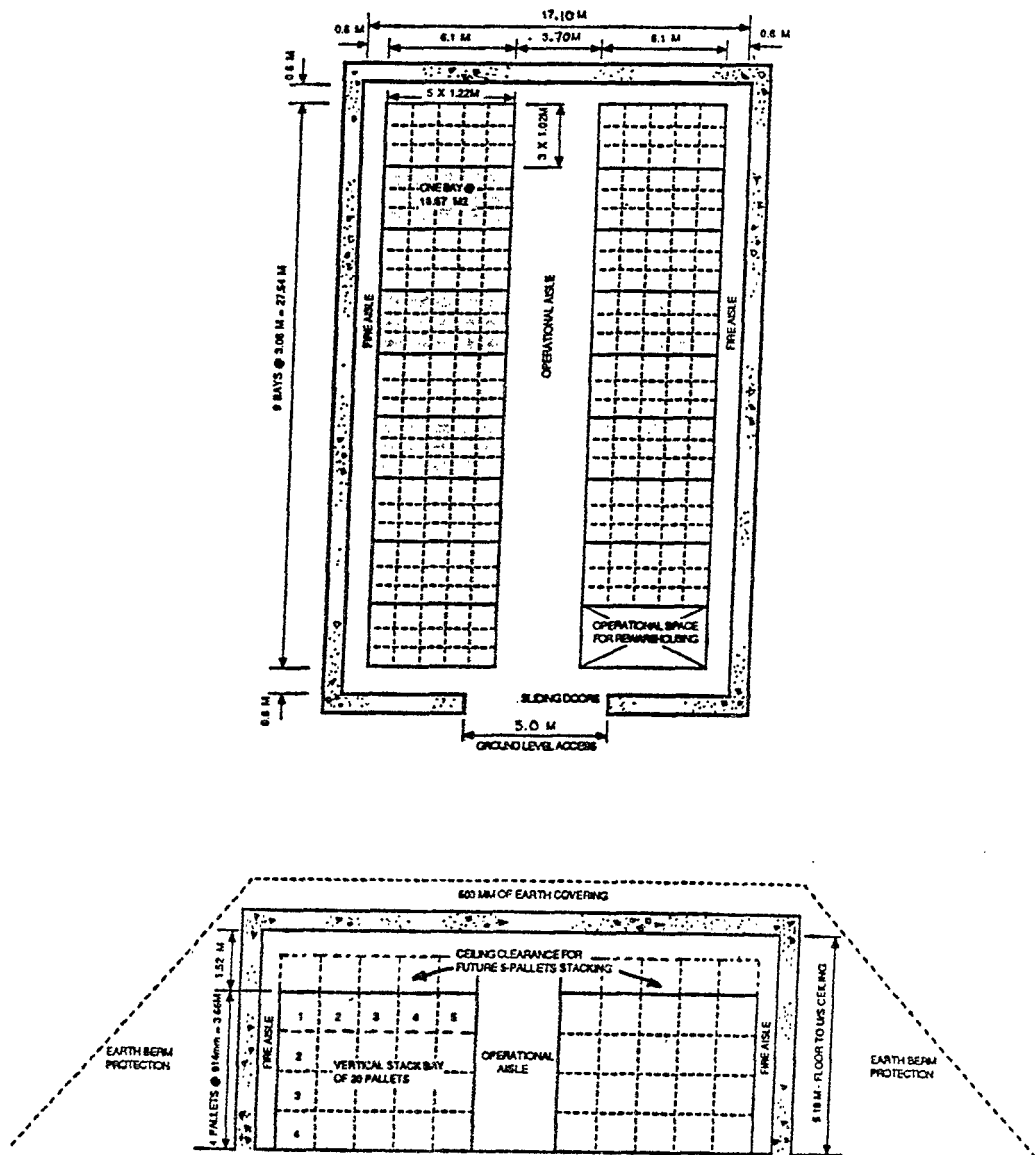
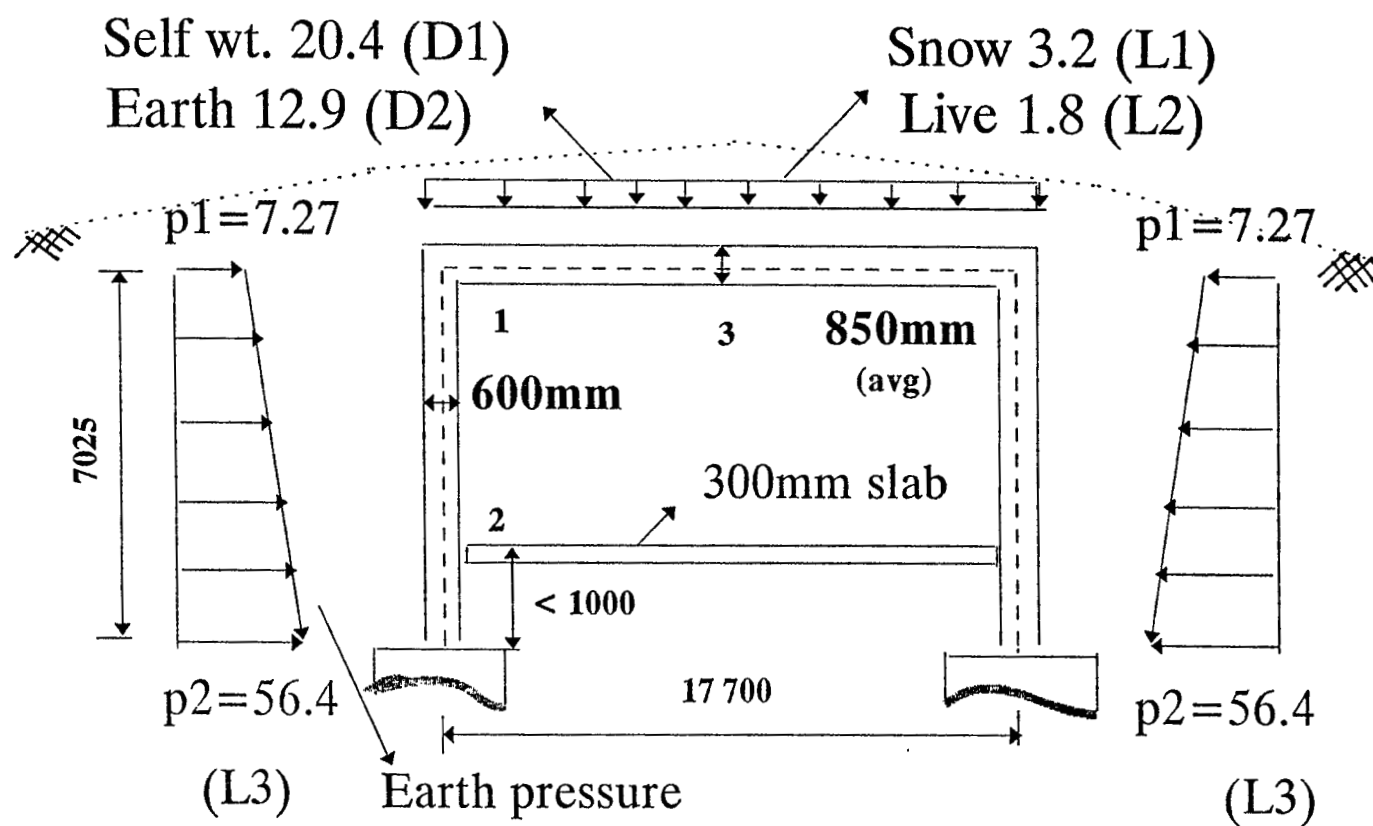


Fig.3 Schematic layout

Fig.4 Details of Standard igloo

# STATIC DESIGN



NOTE: All loads in KN/M

FIG.5



\*\*\* LOAD INITIALIZING DATA \*\*\*

load case	# loaded joints	# support settlements	# loaded members	describe load case
1	0	0	4	SELF WEIGHT
2	0	0	2	EARTH ON SIDE WALL (UDL)
3	0	0	2	EARTH ON SIDE WALL (TRIANGULAR)
4	0	0	2	EARTH ON ROOF
5	0	0	2	SNOW & L.L. ON ROOF (3.2 + 1.8)

Note: Load Case 1 specified as self-weight. Joint and Member load data for Load Case 1 is ignored. Self-weight is automatically calculated.

\*\*\* MEMBER FORCES \*\*\*

Load Case Results								
mem no	load case	Joint no	x-axial kN	y-shear kN	z-shear kN	x-tors'n kN-m	y-moment kN-m	z-moment kN-m
1	1	1	176.779	0.000	-42.343	0.000	297.460	0.000
		2	-275.832	0.000	42.343	0.000	0.000	0.000
	2	1	0.000	0.000	-28.226	0.000	18.895	0.000
		2	0.000	0.000	-22.846	0.000	0.000	0.000
	3	1	0.000	0.000	-66.058	0.000	59.876	0.000
		2	0.000	0.000	-106.546	0.000	0.000	0.000
	4	1	114.165	0.000	-27.345	0.000	192.099	0.000
		2	-114.165	0.000	27.345	0.000	0.000	0.000
	5	1	44.250	0.000	-10.599	0.000	74.457	0.000
		2	-44.250	0.000	10.599	0.000	0.000	0.000
2	1	1	42.842	0.000	176.659	0.000	-297.460	0.000
		3	-42.343	0.000	.120	0.000	-483.731	0.000
	2	1	28.225	0.000	-.080	0.000	-18.895	0.000
		3	-28.225	0.000	.080	0.000	19.600	0.000
	3	1	66.058	0.000	-.187	0.000	-59.876	0.000
		3	-66.058	0.000	.187	0.000	61.528	0.000
	4	1	27.668	0.000	114.087	0.000	-192.099	0.000
		3	-27.668	0.000	.078	0.000	-312.393	0.000
	5	1	10.724	0.000	44.220	0.000	-74.457	0.000
		3	-10.724	0.000	.030	0.000	-121.083	0.000
3	1	3	42.343	0.000	.120	0.000	483.731	0.000
		4	-42.842	0.000	176.659	0.000	297.460	0.000
	2	3	28.225	0.000	.080	0.000	-19.600	0.000
		4	-28.225	0.000	-.080	0.000	18.895	0.000
	3	3	66.058	0.000	-.187	0.000	-61.528	0.000
		4	-66.058	0.000	-.187	0.000	59.876	0.000
	4	3	27.668	0.000	.078	0.000	312.393	0.000
		4	-27.668	0.000	114.087	0.000	192.099	0.000
	5	3	10.724	0.000	.030	0.000	121.083	0.000
		4	-10.724	0.000	44.220	0.000	74.457	0.000

Linear Elastic analysis results

Str No. 01

FIG.6

**\*\*\* LOAD COMBINATION DATA \*\*\***

Load Comb	Load Case	Comb Fact	Load Case	Comb Fact	Load Case	Comb Fact	Load Case	Comb Fact	Load Case	Comb Fact	Load Case	Comb Fact
1	1	1.25	2	1.5	3	1.5	4	1.25				
2	1	1.25	2	1.5	3	1.5	4	1.25	5	1.5		

**Load Combination Results**

mem no	load Comb	Joint no	x-axial kN	y-shear kN	z-shear kN	x-tors'n kN-m	y-moment kN-m	z-moment kN-m
1	1	1	363.681	0.000	-228.536	0.000	730.106	0.000
		2	-487.496	0.000	-106.978	0.000	0.000	0.000
	→ 2	1	430.056	0.000	-244.434	0.000	841.791	0.000
		2	-553.871	0.000	-91.080	0.000	0.000	0.000
	1	1	229.562	0.000	363.034	0.000	-730.106	0.000
		3	-228.938	0.000	.647	0.000	-873.462	0.000
→ 2	2	1	245.648	0.000	429.363	0.000	-841.791	0.000
		3	-245.024	0.000	.692	0.000	-1,055.086	0.000
3	1	3	228.938	0.000	.647	0.000	873.462	0.000
		4	-229.562	0.000	363.034	0.000	730.106	0.000
	2	3	245.024	0.000	.692	0.000	1,055.086	0.000
		4	-245.648	0.000	429.363	0.000	841.791	0.000
4	1	4	363.681	0.000	228.536	0.000	-730.106	0.000
		5	-487.496	0.000	106.978	0.000	0.000	0.000
	2	4	430.056	0.000	244.434	0.000	-841.791	0.000
		5	-553.871	0.000	91.080	0.000	0.000	0.000

**Notes:**

1. Positive axial forces act in the positive local (member) x direction.
2. Positive shear forces act in the positive local (member) y,z directions.
3. Pos. moments act in Pos. local x,y,z directions using Right Hand Rule.
4. Reduce above values from roof loadings by factor 0.9 to allow for two-way roof slab action.

**Load Combination Results**

jt no	load comb	X-displ mm	Y-displ mm	Z-displ mm	X-rot'n radians	Y-rot'n radians	Z-rot'n radians
1	1	.0391	0.0000	-.1811	0.00000	.00214	0.00000
	2	.0347	0.0000	-.2094	0.00000	.00266	0.00000
2	1	0.0000	0.0000	0.0000	0.00000	-.00026	0.00000
	2	0.0000	0.0000	0.0000	0.00000	-.00052	0.00000
3	1	0.0000	0.0000	-17.0699	0.00000	0.00000	0.00000
	2	0.0000	0.0000	-20.7923	0.00000	0.00000	0.00000
1	1	-.0391	0.0000	-.1811	0.00000	-.00214	0.00000
	2	-.0347	0.0000	-.2094	0.00000	-.00266	0.00000
5	1	0.0000	0.0000	0.0000	0.00000	.00026	0.00000

Linear Elastic analysis results

Str No. 01

FIG.7

**RESULTS**  
**(STATIC DESIGN)**

ELEMENT	FLEXURE + AXIAL		SHEAR	
	Actual Rft. (mm <sup>2</sup> /m)	Required Rft. (mm <sup>2</sup> /m)	Actual (mpa)	Allowable (mpa)
Walls (one-way)	2500	2300	0.56	0.99
Roof (two-way)	6000	6200	0.65	0.93

FIG. 8

## FREE FIELD BLAST PRESSURE (227,000 KG)

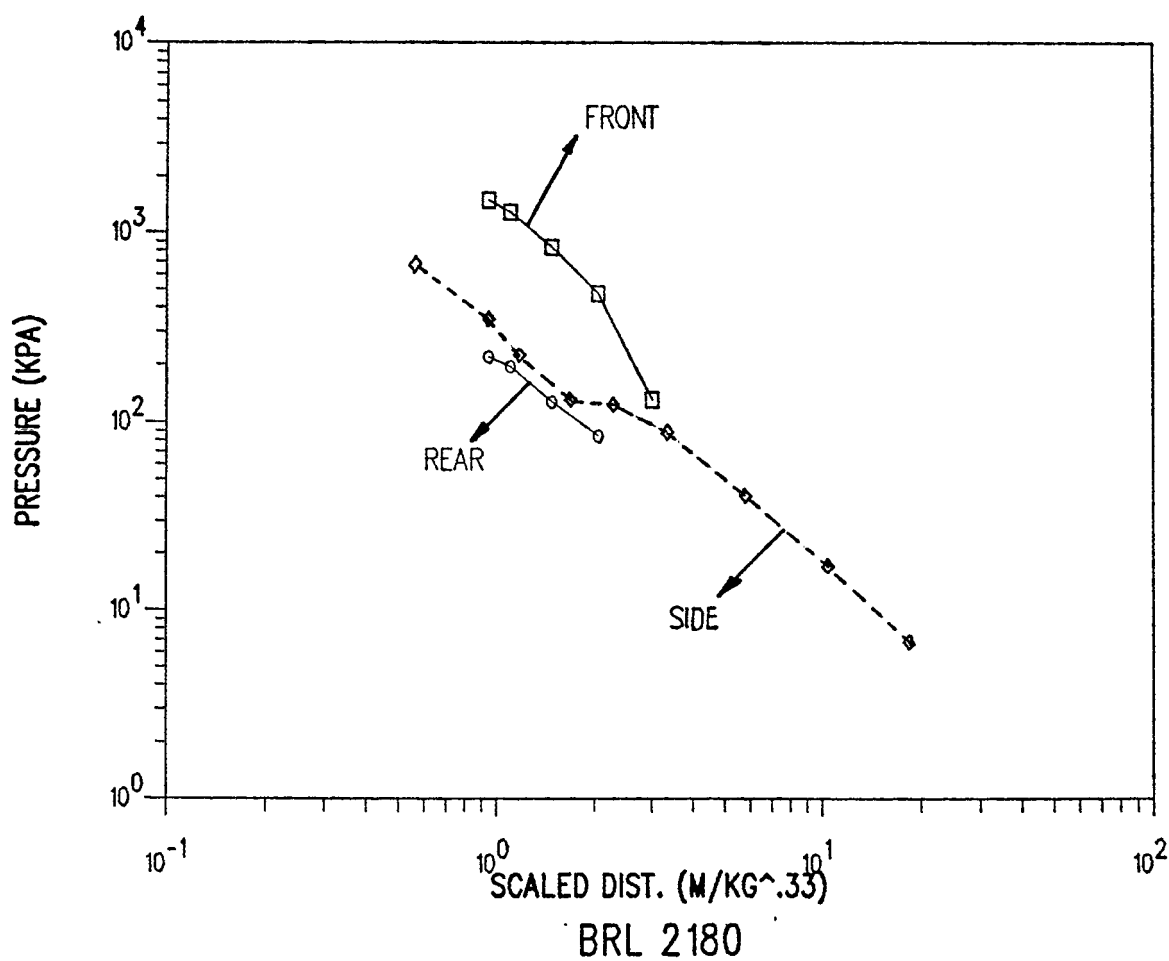


FIG. 9

# FREE FIELD BLAST IMPULSE (227,000 KG)

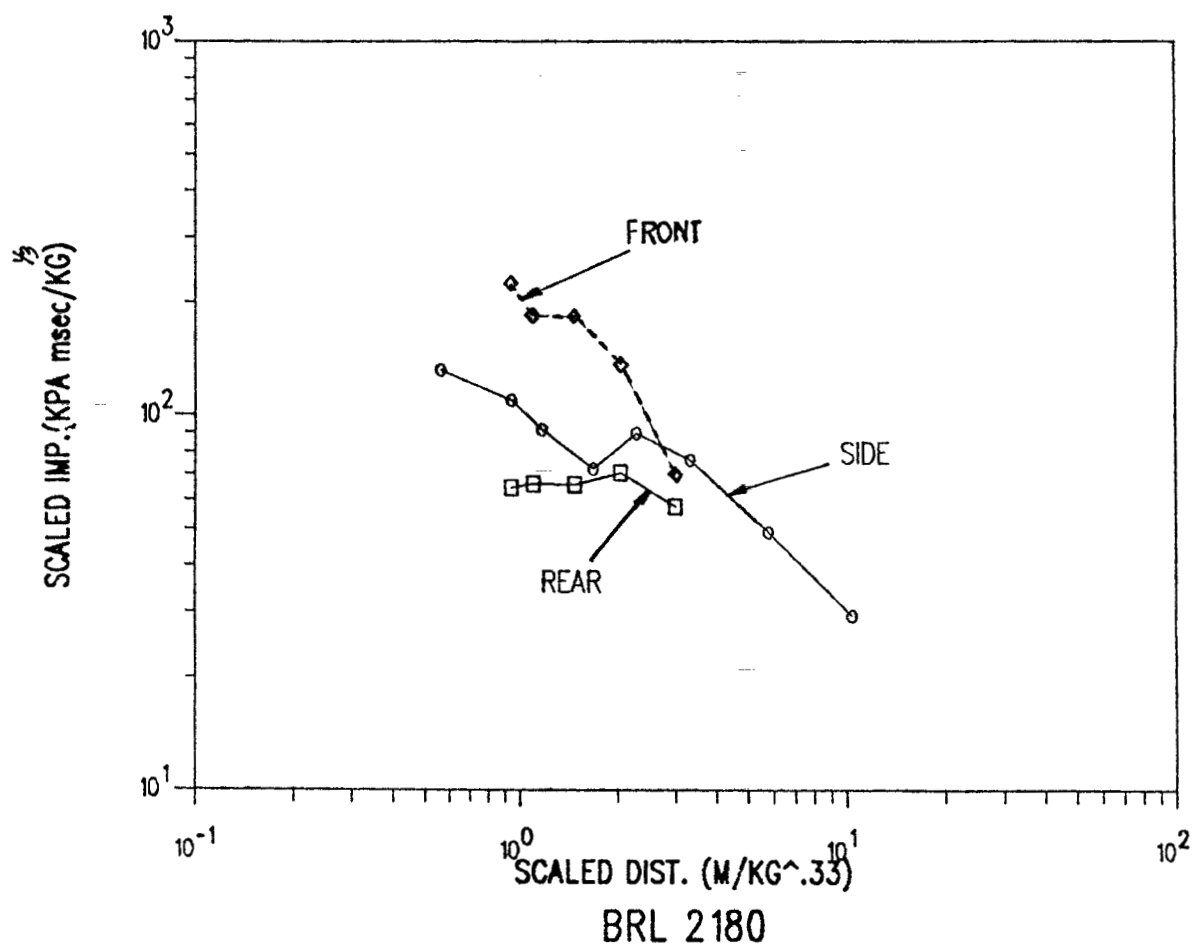


FIG. 10

# FREE FIELD BLAST PRESSURE (250,000 KG)

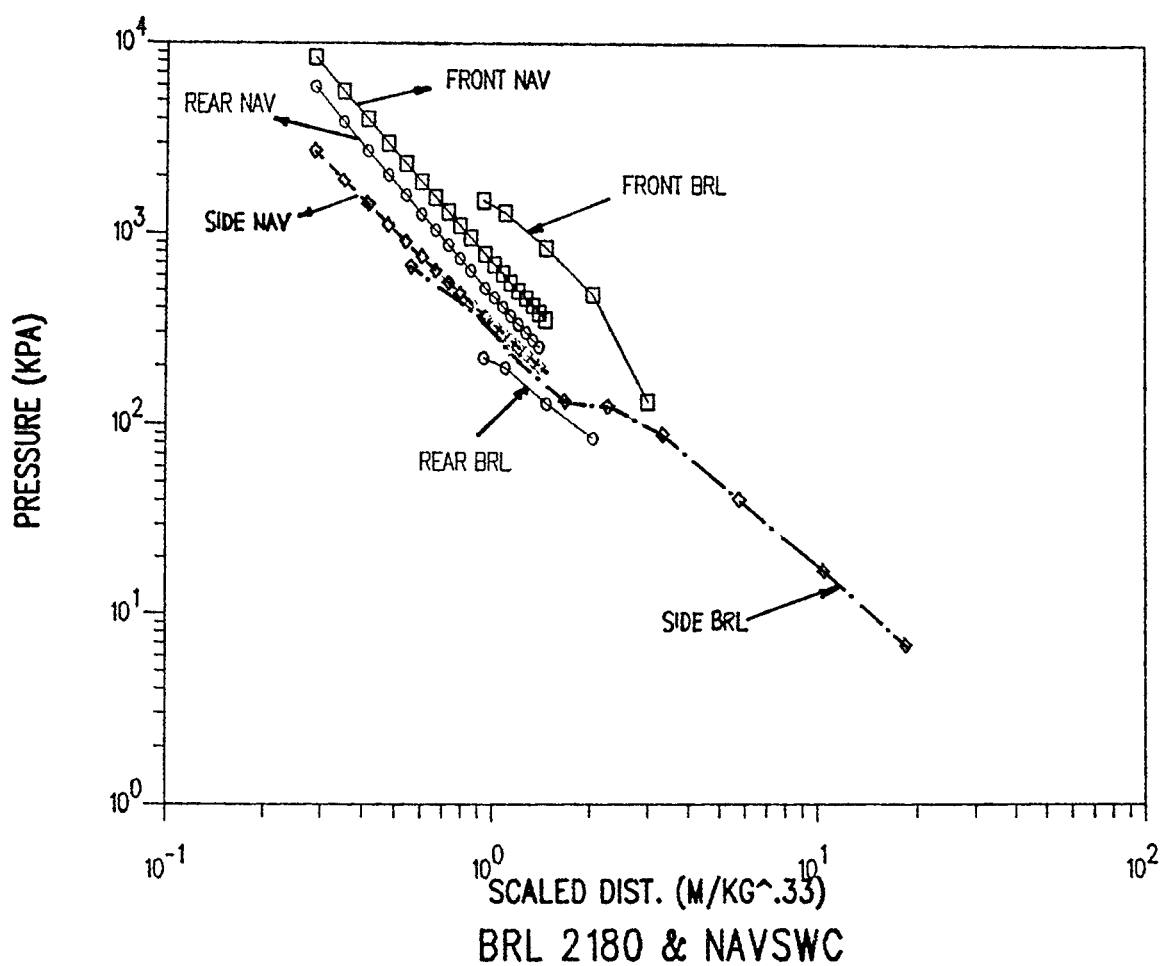


FIG. 11

# FREE FIELD BLAST IMPULSE (250,000 KG)

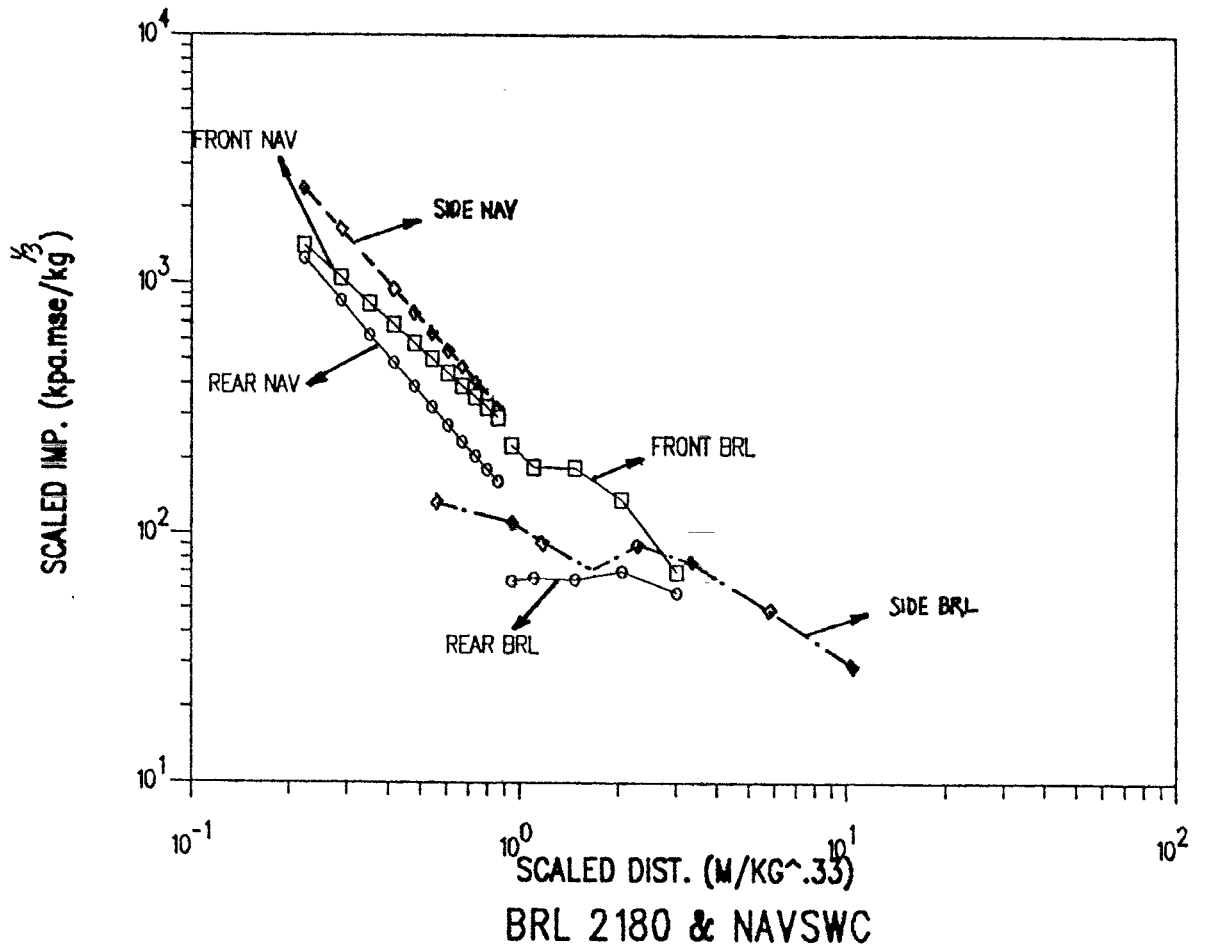


FIG. 12

## IGLOO LAYOUT

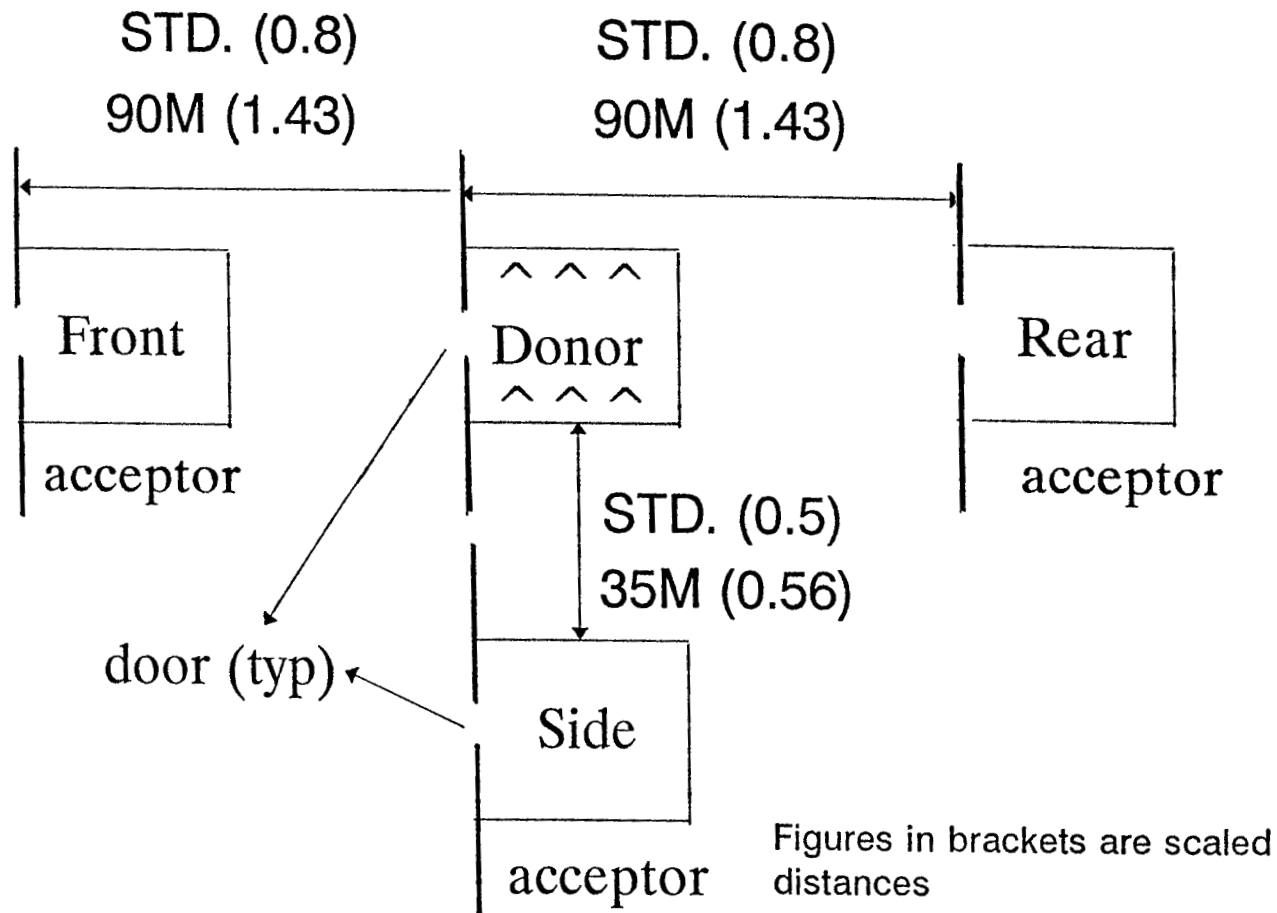


FIG.13



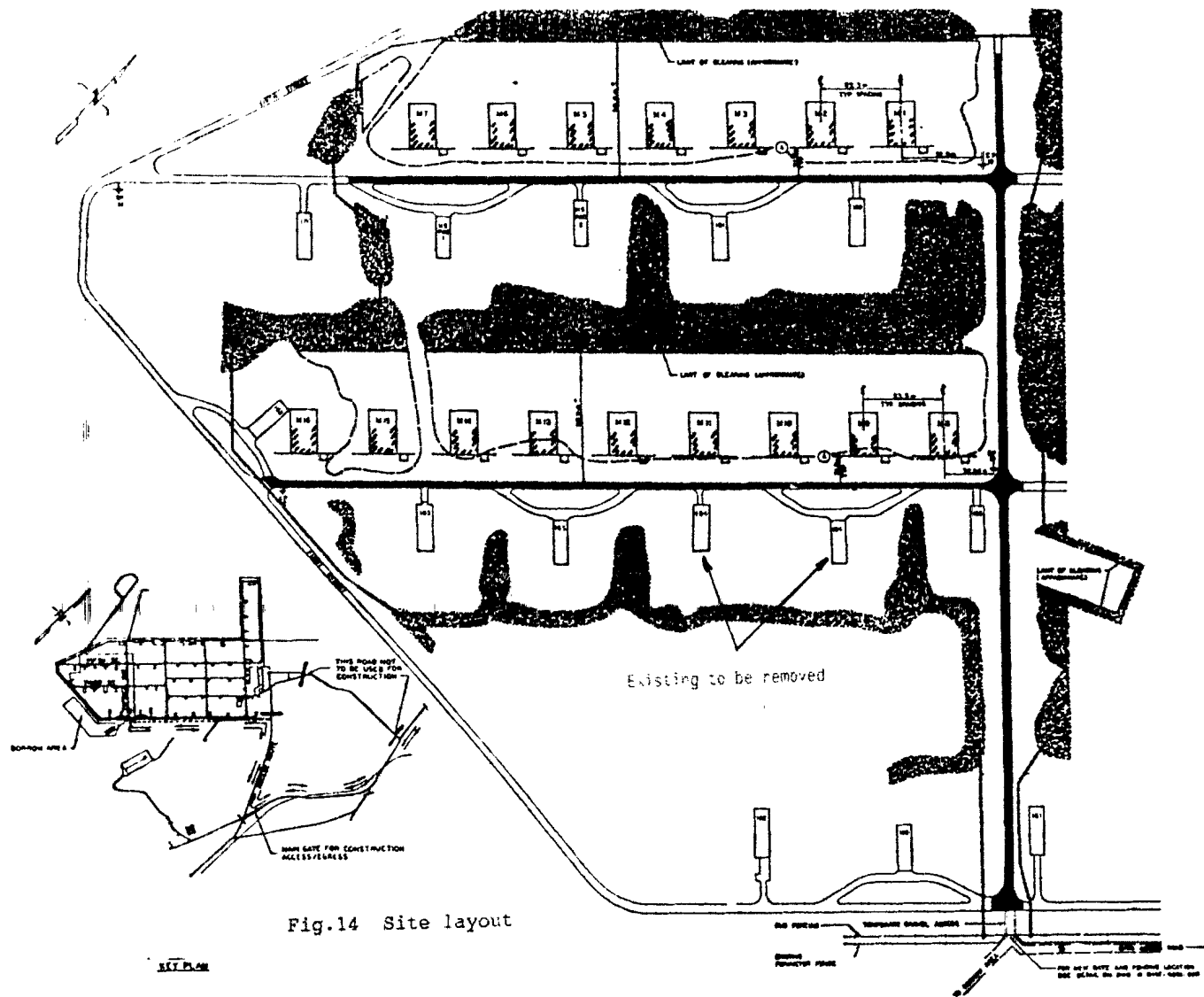


Fig.14 Site layout

## DYNAMIC DESIGN

### (BLAST LOADS)

- (1) STANDARD IGLOO HAS BEEN DESIGNED (DYNAMICALLY) AS "ACCEPTOR" STRUCTURES FOR THE FOLLOWING MAXIMUM BLAST LOADS AT MINIMUM SEPARATION DISTANCES OF 35M (SIDE TO SIDE) AND 90M (FRONT TO REAR) BETWEEN IGLOOS, WITH EXPLOSIONS OCCURRING ACCIDENTALLY IN ADJACENT IGLOOS, TERMED AS "DONOR" STRUCTURES:

ELEMENTS OF "ACCEPTOR"	LOCATION OF "DONOR"	PRESSURE (KPa)	IMPULSE (KPa MSEC)	DURATION (MSEC)
. HEADWALL & FRONT DOOR	REAR	420	7,980	38
	FRONT	275	11,825	86
	SIDE	400	7,600	38
. SIDEWALL	REAR	550	9,625	35
	FRONT	70	4,550	130
	SIDE	530	7,950	30
. REARWALL	REAR	700	10,850	31
	FRONT	50	4,400	176
	SIDE	400	7,600	38
. ROOF SLAB	REAR	550	9,625	35
	FRONT	70	4,550	130
	SIDE	400	7,600	38
. SLAB ON GRADE (LIVE LOAD) 50 KPa				
NOTE: 100 KPa = 1 BAR				

FIG.15

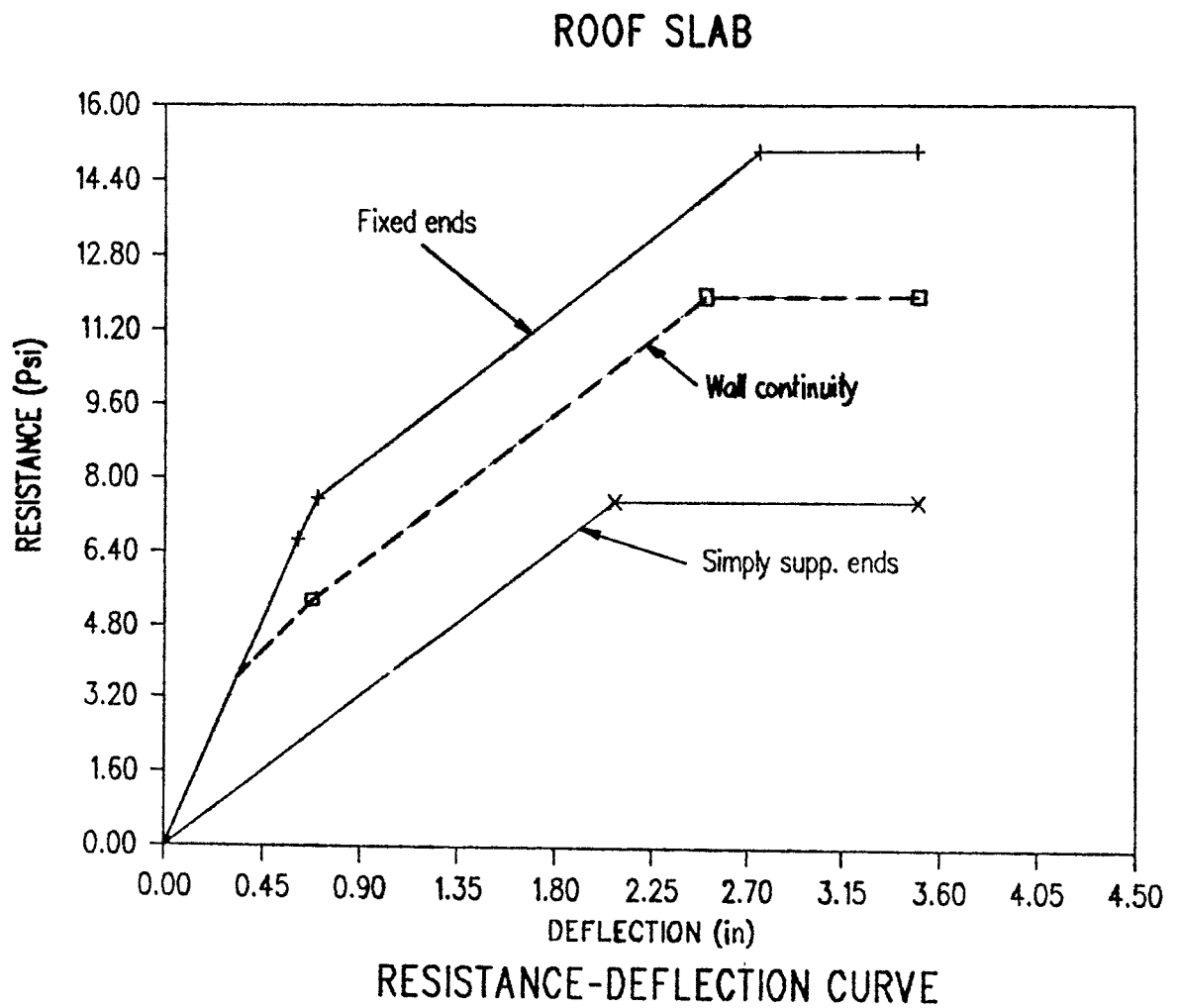


FIG. 16

## ROOF SLAB

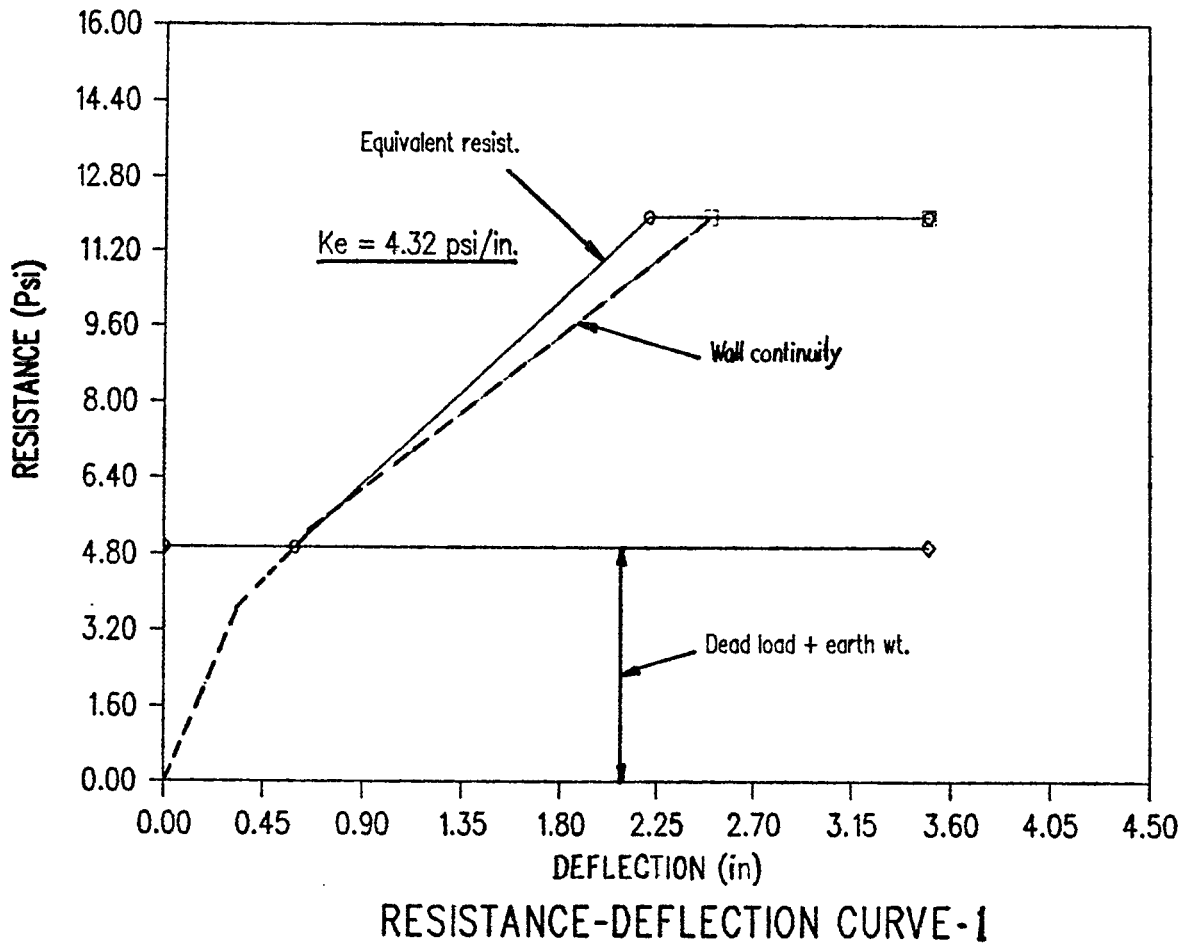
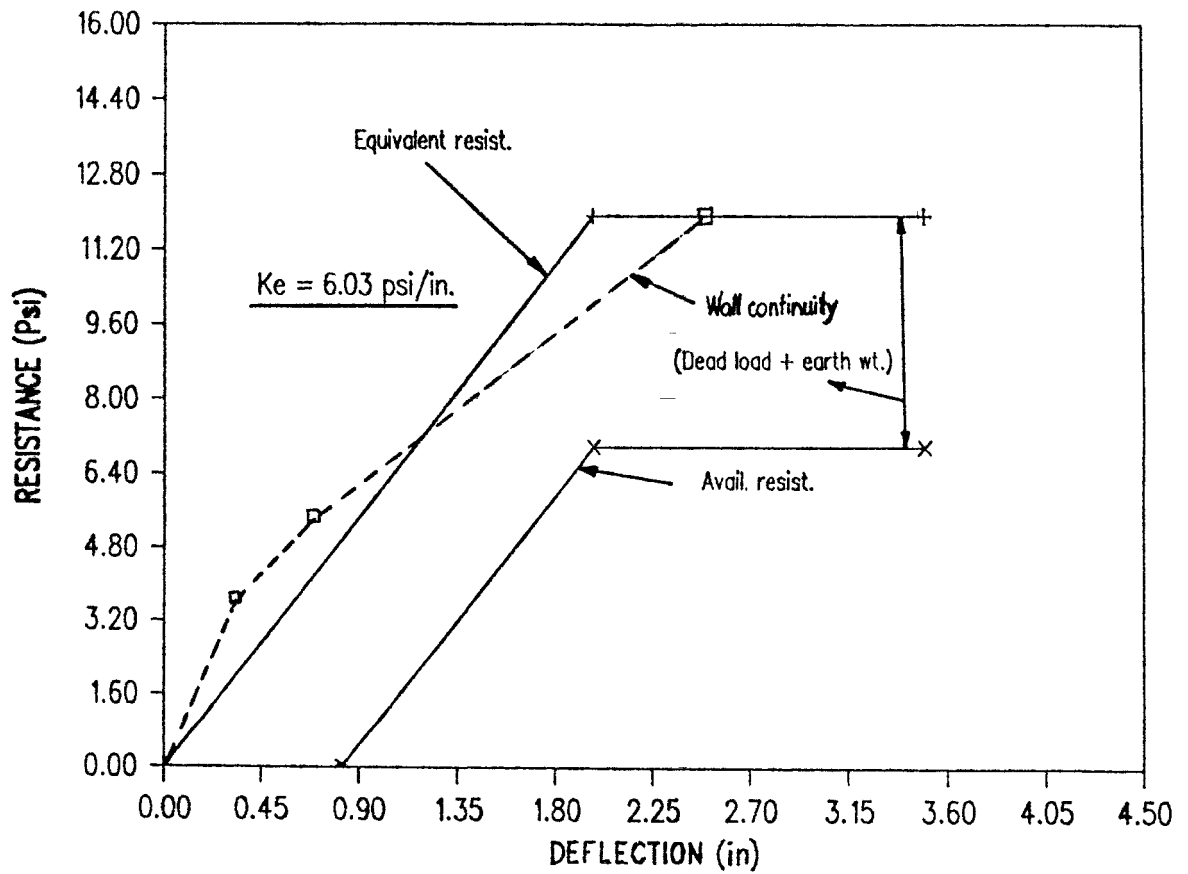


FIG. 17

## ROOF SLAB

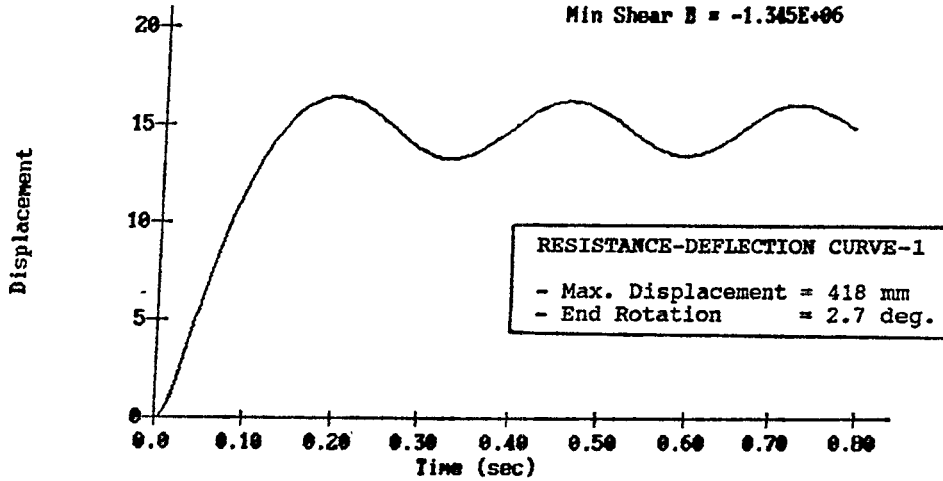


RESISTANCE-DEFLECTION CURVE - 2

FIG. 18

# Roof Slab

Equiv. Elastic Displac. = 1.618E+00	Max Force = 6.559E+07
Max Displacement = 1.645E+01	Min Force = 0.000E+00
Min Displacement = 6.066E-02	Max Resistance = 5.731E+06
Time of Max Displacement = 1.960E-01	Min Resistance = -5.381E+06
Time of Min Displacement = 3.500E-03	Max Shear A = 2.973E+06
MU = 1.016E+01	Min Shear A = -5.381E+05
	Max Shear B = 5.957E+06
	Min Shear B = -1.345E+06



# Roof Slab

Equiv. Elastic Displac. = 1.159E+00	Max Force = 6.559E+07
Max Displacement = 1.581E+01	Min Force = 0.000E+00
Min Displacement = 6.060E-02	Max Resistance = 5.731E+06
Time of Max Displacement = 1.925E-01	Min Resistance = -5.381E+06
Time of Min Displacement = 3.500E-03	Max Shear A = 2.982E+06
MU = 1.364E+01	Min Shear A = -5.381E+05
	Max Shear B = 5.978E+06
	Min Shear B = -1.345E+06

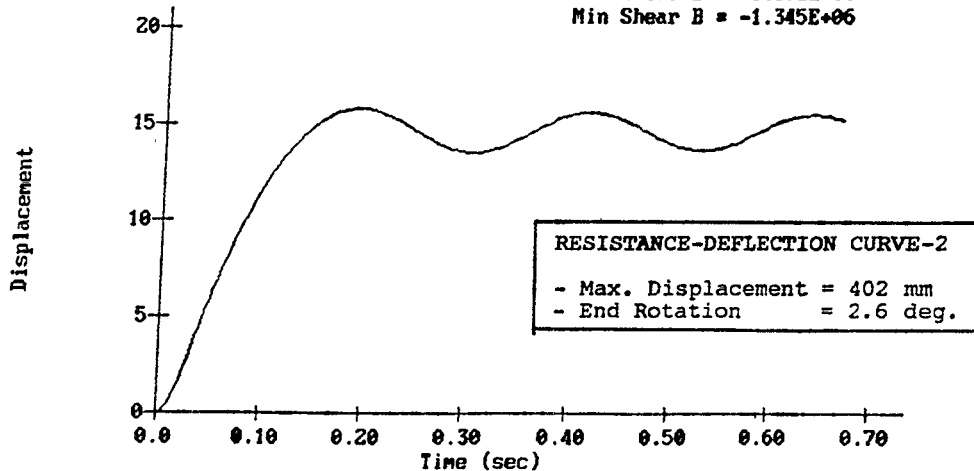
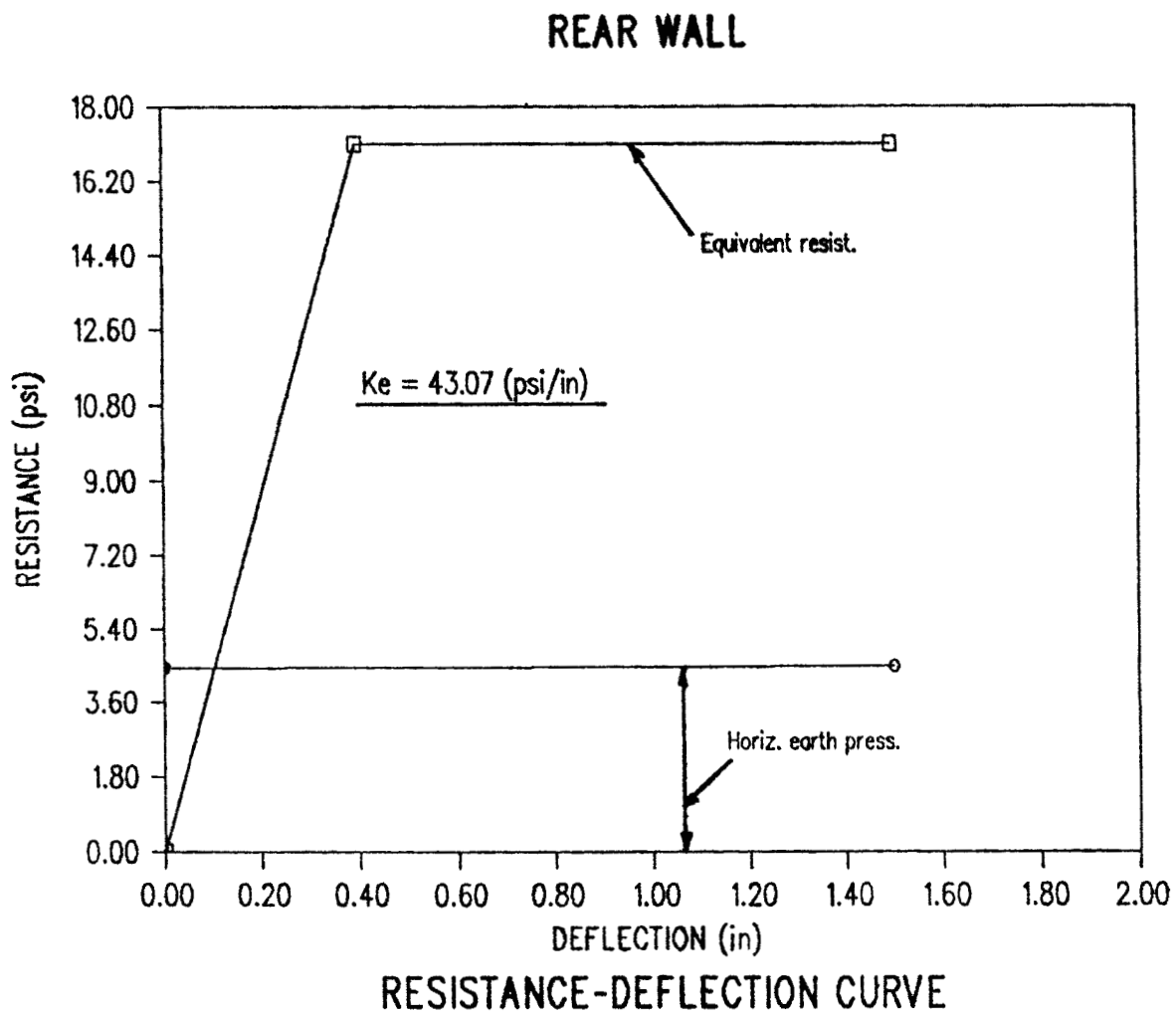


FIG.19



**FIG. 20**

**RESULTS**  
**(DYNAMIC DESIGN)**

<b>ELEMENT</b>	<b>SIZE</b>	<b>FLEXURE + AXIAL</b>		<b>SHEAR</b>	
		<b>Max displ. (mm)</b>	<b>End rotation (degrees)</b>	<b>Actual (mpa)</b>	<b>Allowable (mpa)</b>
<b>Roof Slab</b>	850 mm thick 30M @ 200 & 25M @ 200 (top & bot. bothways)	402	2.6	1.19	1.11
<b>Side Walls</b>	600 mm thick 25M @ 200 (vert.) 15M @ 200 (horz.)	221* {120}	3.7* {2}	0.99	0.99
<b>Rear Walls</b>	600 mm thick 30M @ 200 (vert.) 15M @ 200 (horz.)	222* {121}	3.7* {2}	1.25	0.99
<b>Front Wall</b>	600 mm thick 30M @ 200 (vert.) 25M @ 200 (horz.)	37	0.9	0.95	0.99
<b>Door</b>	W 250 x 39 @ 400 8 mm plates-2nos	122	2.6	379 kn	388 kn

NOTES:    • Figures allow for mass of earth = 1.2m width behind wall.  
             { } Figures in brackets allow for mass of earth = 1/2 height of wall behind wall.

Fig.21



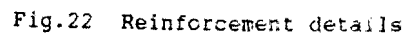


Fig.23 Sliding door details

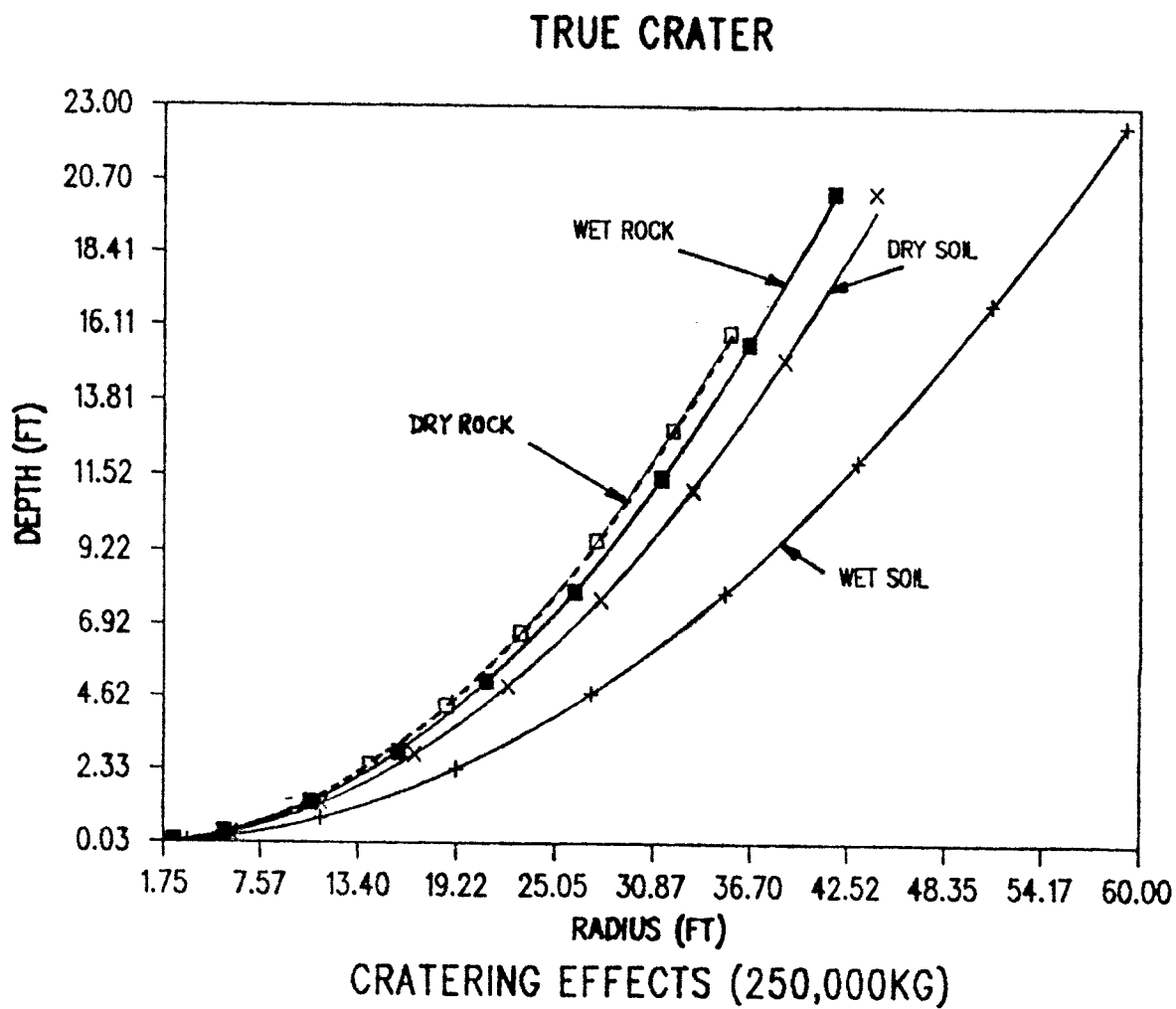


Fig.24

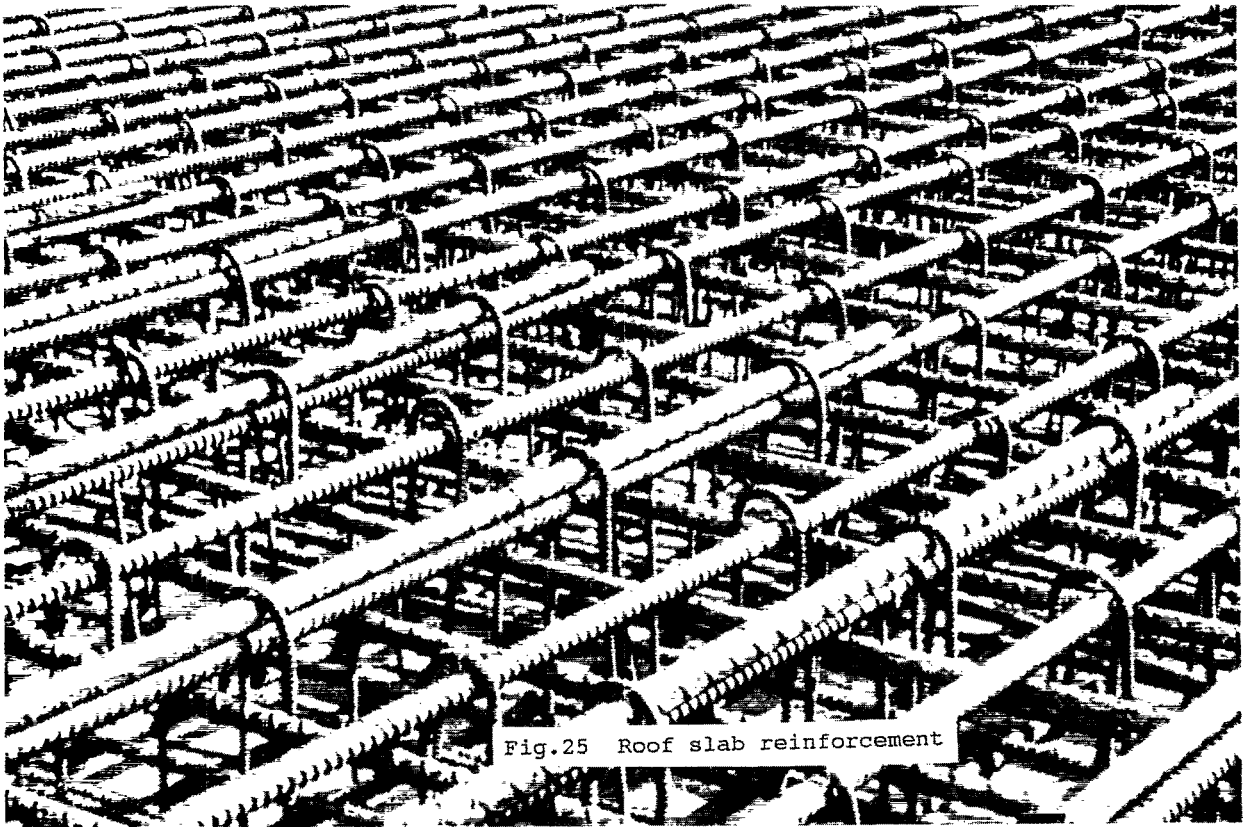


Fig.25 Roof slab reinforcement

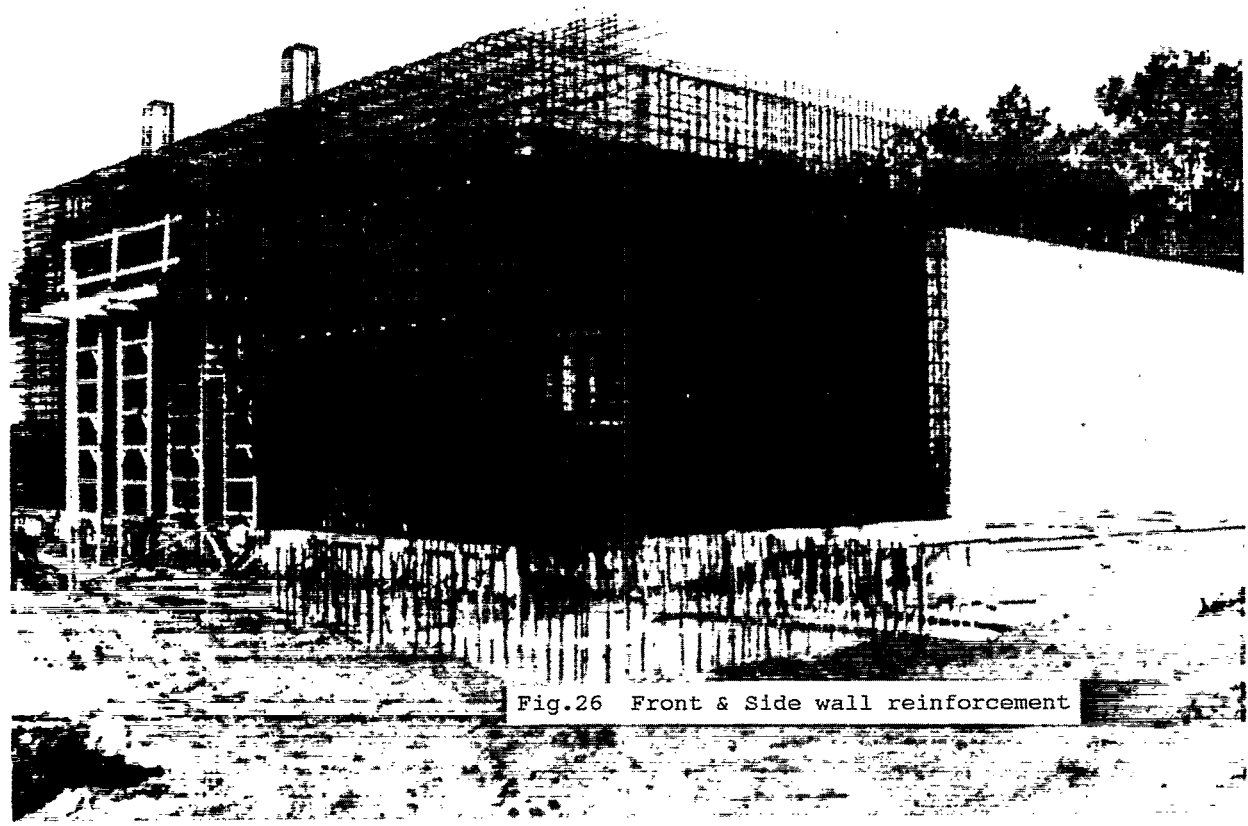


Fig.26 Front & Side wall reinforcement

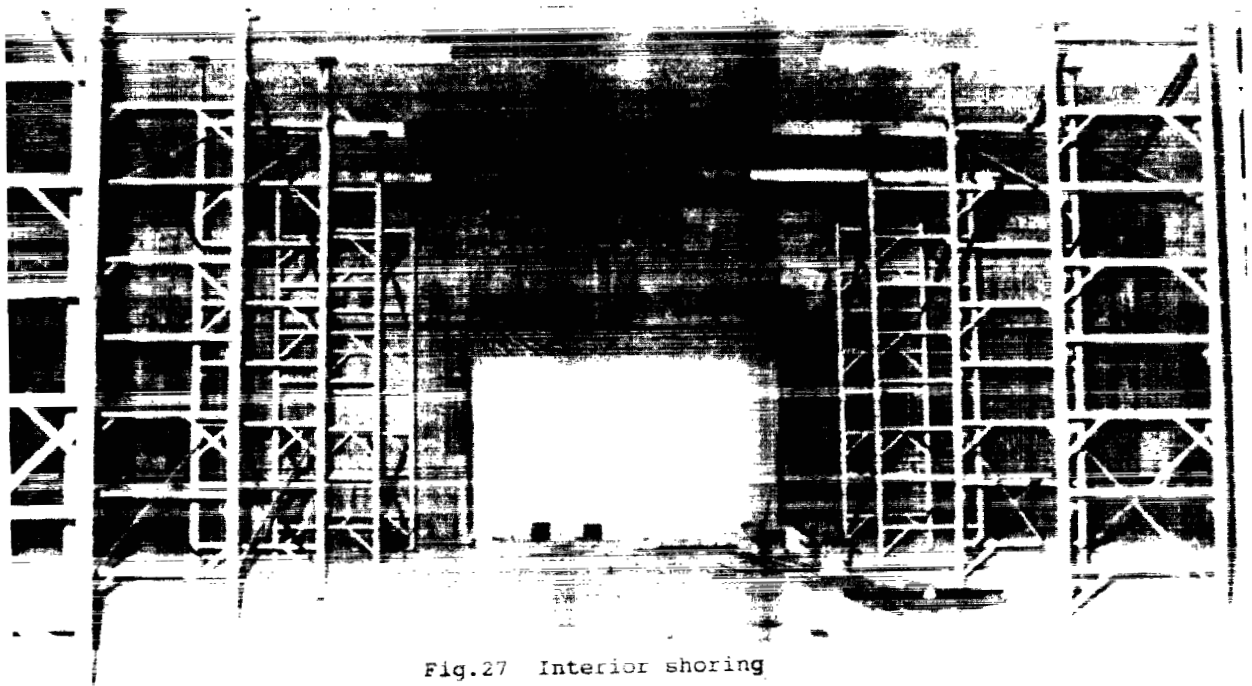


Fig.27 Interior shoring



Fig.28 Sliding door



Fig.29 General view

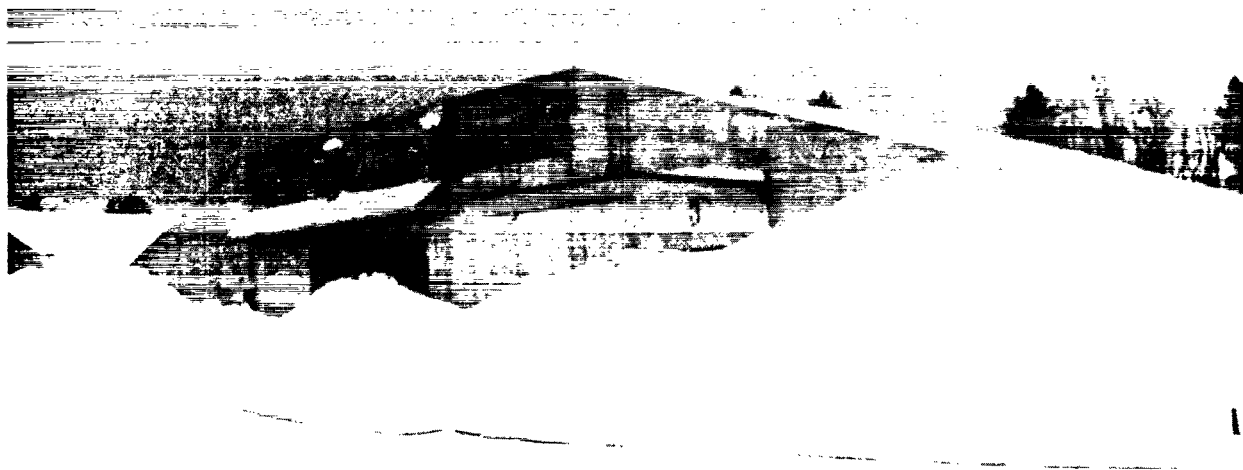


Fig.30 Snow covered igloo

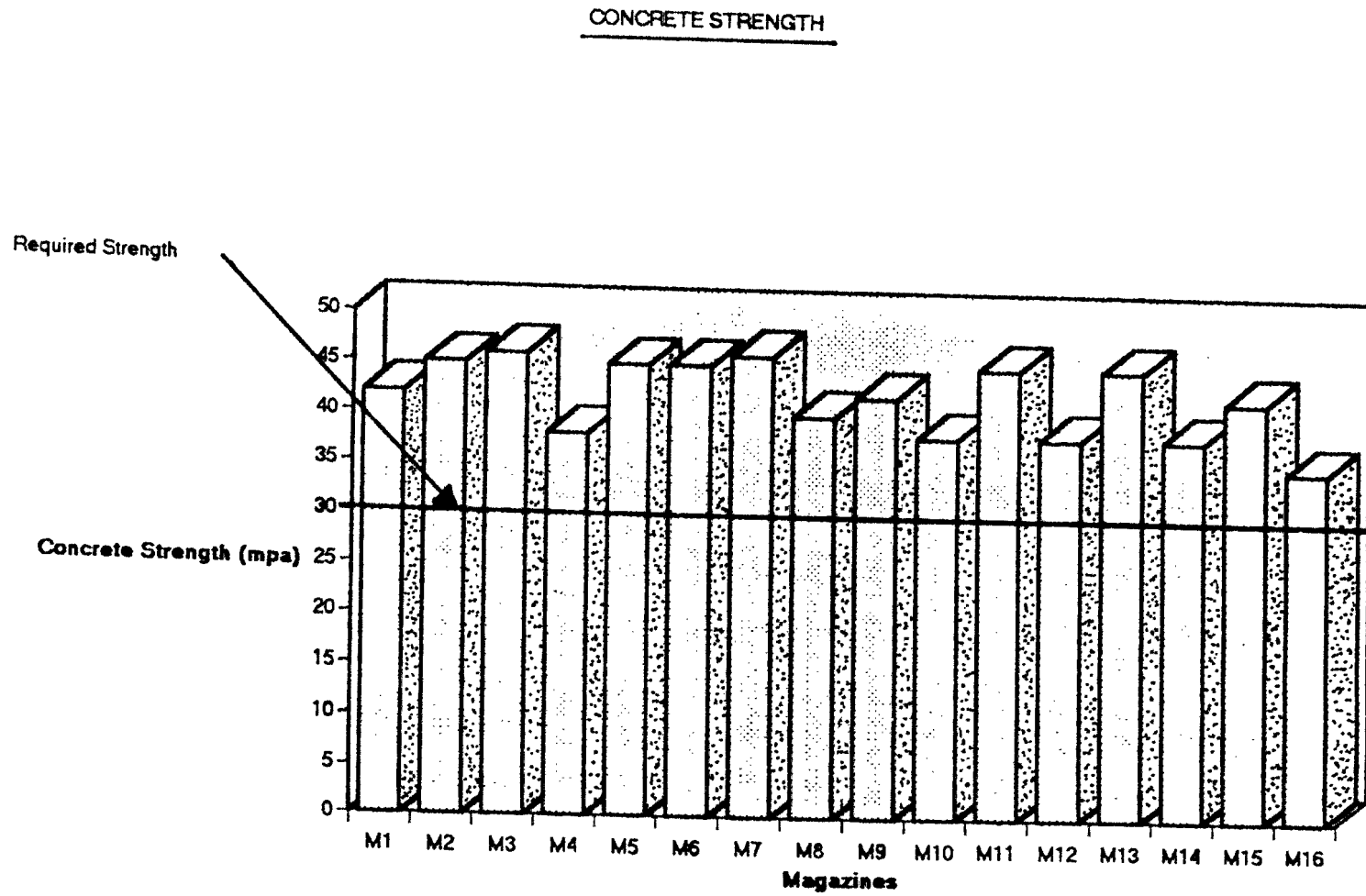


Fig.31

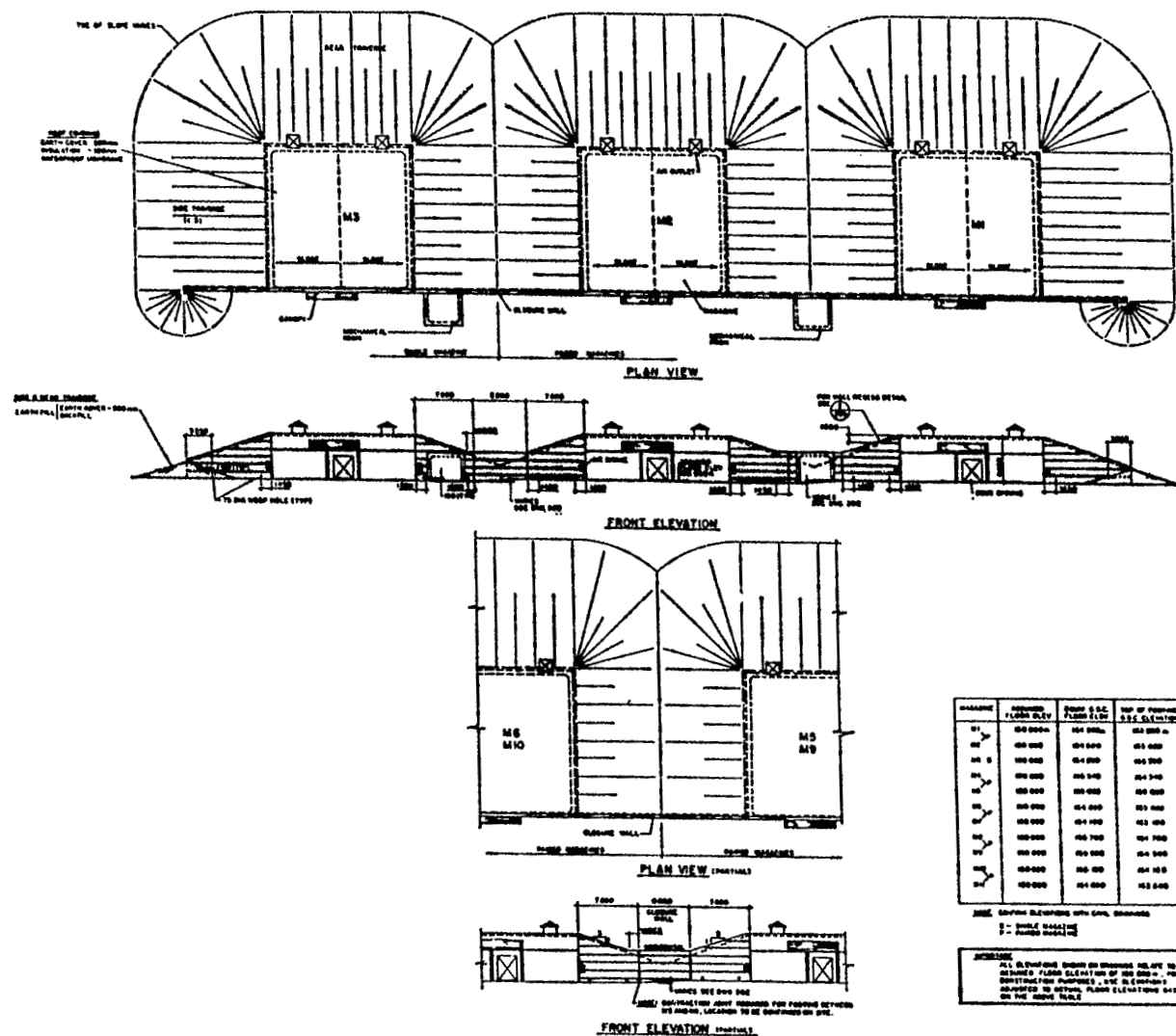


Fig.32 40,000 kg. NEQ igloos - plan



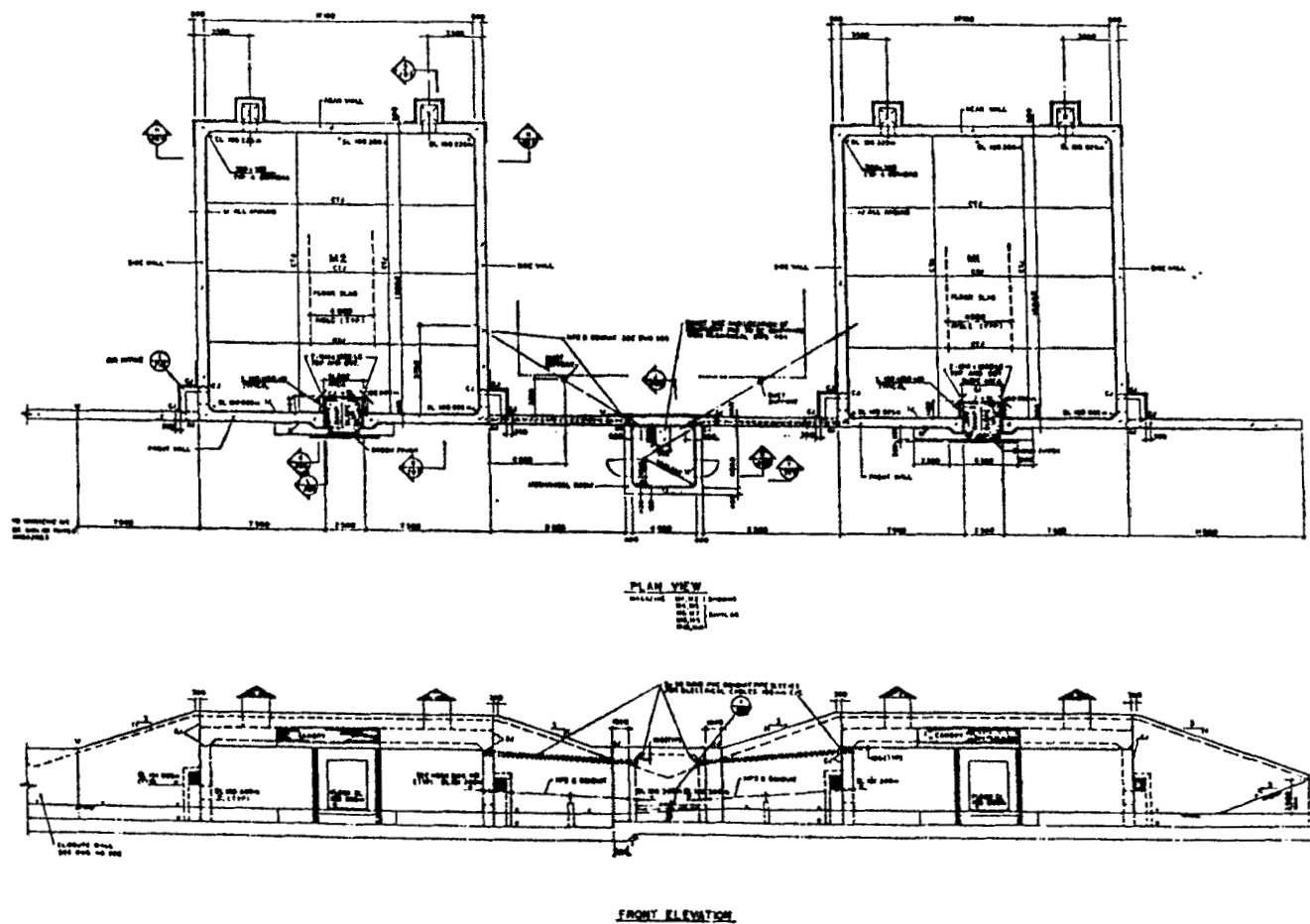


Fig.33 40,000 kg. NEQ igloos - details

## CANADIAN IGLOOS

### UNIT COSTS

SIZE(W,L,H)m ( NOS.)	VOLUME (Cu.M)	NEQ/IGLOO (Kg)	COST/ (Cu.M)	COST/ (Kg of NEQ)	REMARKS
18X15.9X4.9 ( 1 )	1398	75000	\$ 539	\$ 10.04	* Consn.1987 * Crane
16.8X18X6 ( 4 )	1814	45000	\$ 378	\$ 15.00	* Consn.1990 * Crane
17.1X28.7X5.6 ( 1 )	2748	250000	\$ 405	\$ 4.50	* Consn.1990
17.1X28.7X5.6 ( 16 )	2748	250000	\$ 330	\$ 3.63	* Consn.1990

Fig.34